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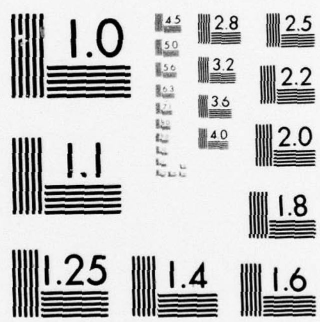

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The research concerned a survey of existing literature on supersonic diffusers, and experimental study on pressure recovery of supersonic diffusers in a variety of facilities with a variety of configurations following a contoured Mach Number = 3 nozzle. The nozzle and test section were free of models and the diffusers were either of constant cross section (straight duct), or of variable cross section, and they were generally patterned to be representative of some classes of gasdynamic laser nozzles. The optimum pressure recovery of the operating facility and the minimum pressure recovery required to start supersonic flow at →

the nozzle end were determined. The facilities used were a small continuous operation supersonic wind tunnel and a Ludwieg tube operating as a blow down wind tunnel with a steady state in the millisecond region. The nominal Mach number quoted above was varied by varying Reynolds numbers in the range $10^4 < Re < 10^5$ and the diffuser length was changed systematically from values of 15 to 60 times the hydraulic diameter of the nozzle exit. Careful correlation with data from other facilities taken under different circumstances was performed, while a number of the results found were unique to the current investigation.

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DEPARTMENT OF ENGINEERING
AND APPLIED SCIENCE

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18 March 1977

FROM: Peter P. Wegener, Principal Investigator

TO: Air Force Office of Scientific Research

SUBJECT: FINAL REPORT on CONTRACT F44620-73-C-0032
"SUPERSONIC DIFFUSER RESEARCH"

The research concerned a survey of existing literature on supersonic diffusers, and experimental study on pressure recovery of supersonic diffusers in a variety of facilities with a variety of configurations following a contoured Mach number = 3 nozzle. The nozzle and test section were free of models and the diffusers were either of constant cross section (straight duct), or of variable cross section, and they were generally patterned to be representative of some classes of gasdynamic laser nozzles. The optimum pressure recovery of the operating facility and the minimum pressure recovery required to start supersonic flow at the nozzle end were determined. The facilities used were a small continuous operation supersonic wind tunnel and a Ludwieg tube operating as a blow down wind tunnel with a steady state in the millisecond region. The nominal Mach number quoted above was varied by varying Reynolds numbers in the range $10^4 < Re < 10^5$ and the diffuser length was changed systematically from values of 15 to 60 times the hydraulic diameter of the nozzle exit. Careful correlation with data from other facilities taken under different circumstances were performed, while a number of the results found were unique to the current investigation.

The results of the research are described in detail in the reports and journal publications produced under the subject contract which are listed at the end of this final report. A literature survey was first carried out and it was noted that systematic studies of diffuser length, starting pressure ratios for different configurations, etc. were remarkably absent since most investigations were concerned with a specific type of equipment attached to a specific facility, usually a supersonic wind tunnel. The primary results of our investigations can be summarized by stating that in constant area diffusers, pressure recoveries up to about 80% of normal shock were achieved. The flexible walled diffusers investigated increased the pressure recovery to about 94% with the corresponding cost in more complicated mechanical devices to operate such a movable diffuser. It was further shown that in contrast to the often used Reynolds number referred to the hydraulic diameter of the nozzle exit, the essential parameter taking care of the viscous boundary layer effects is a dimensionless boundary layer displacement thickness at the entrance of the diffuser. This dimensionless parameter is given by the ratio of this displacement thickness to the hydraulic diameter and its values were varied from 0.04 to 0.2. Pressure recoveries obtainable in diffusers of remarkable differences in size, up to those of large wind tunnels, could be well correlated using this new parameter. Additional improvements in diffuser performance were achieved, again at the cost of further mechanical complication, by applying boundary layer suction at the exit of the nozzle.

Studies of the starting process of the supersonic flow were performed primarily in the Ludwieg tube facility. Here upstream and downstream diaphragms were used, and it was seen that a much shorter starting period could be achieved with the upstream diaphragm. The starting time in this context is the time elapsed between the arrival of a first pressure or expansion wave at a given location, to the time at which the steady state is observed at the same location. These observations were made by transient pressure measurements as well as by high speed shadowgraph and schlieren photography. It was seen that a useful compromise could be found by optimizing pressure recovery and at the same time having short starting periods. The open questions remaining at this time concern primarily if large aspect (width to height) ratios of diffusers effect pressure recovery strongly. This effect will be studied by subdividing the square (2 in. × 2 in.) cross section of the straight duct diffuser into a series of narrow rectangular ducts. This work is currently in progress.

Publications, AFOSR Grant F44620-73-C-0032

1) CONTRACT REPORTS

Report #1 Joseph A. Johnson III and Benjamin J.C. Wu, "Pressure Recovery and Related Properties in Supersonic Diffusers, A Review," (April 1974), AFOSR-TR-75-1551, ADA 017631.

Report #2 Peter E. Merkli, "Pressure Recovery in Constant Area Supersonic Diffusers," (September 1974).

Report #3 Peter E. Merkli, "Pressure Recovery in Rectangular Adjustable Area Supersonic Diffusers," (April 1975), AFOSR-TR-76-1238, ADA 033630.

Report #4 Peter E. Merkli, "Pressure Recovery in Rectangular Constant Area Supersonic Diffusers," (November 1975)

Report #5 Peter E. Merkli and Nesim Abuaf, "The Flow Starting in Constant Area Supersonic Diffusers in a Ludwieg Tube," (September 1976), AFOSR-TR-76-1236, ADA 033317.

Report #6 Nesim Abuaf, "Straight Duct Supersonic Diffuser Flow in a Ludwieg Tube with Upstream Diaphragm," (December 1976), ADA # applied for.

Report #7 Nesim Abuaf and J.R. Soltysiak, "Starting and Pressure Recovery in Nonequilibrium Supersonic Diffuser Flow in a Ludwieg Tube," (in preparation).

2) JOURNAL PUBLICATIONS, ETC.

1. Joseph A. Johnson III, "Nonequilibrium Phenomena in the Pressure Recovery of Supersonic Diffusers," (ABSTRACT) Bull. APS, Vol. 18, No. 11, 37, p. 1483 (November 1973).

2. Joseph A. Johnson III and Benjamin J.C. Wu, "Pressure Recovery in Supersonic Diffusers," Trans. ASME, J. of Fluids Engineering, Vol. 97, Series 1, pp. 374-376, (September 1975). Errata, ibid. p. 533 (December 1975).

3. Peter E. Merkli, "Pressure Recovery in Rectangular Constant Area Supersonic Diffusers," AIAA J. Vol. 14, No.2, pp. 168-172, (February 1976).

4. Peter E. Merkli and Nesim Abuaf, "Starting Times of Supersonic Flow in a Ludwieg Tube with Constant Area Diffusers," submitted to AIAA J.

5. Nesim Abuaf, "Starting of Constant Area, Square Supersonic Diffusers in a Ludwieg Tube," submitted to Eleventh International Symposium on Shock Tubes and Waves, Seattle,Washington, 11-14 July 1977.